maintain themselves far from thermodynamic equilibrium. One contribution is the recognition of self-organizing chemical systems such as the Belousov–Zhabotinskii (B–Z) reaction in which simple component reactions together give rise to complex patterns. Ilya Prigogine coined the term *dissipative structures* for constantly changing, highly organized systems (Nicolis & Prigogine, 1977). Such order depends on a constant flow of energy through the system, which is employed to create order but then dissipates as heat. Dissipative structures such as the B–Z reaction, however, can neither procure for themselves the needed energy flow to maintain themselves far from equilibrium nor the chemicals needed to continue the reactions. Hence, they soon terminate. In the early 1970s, Francisco Varela and Humberto Maturana introduced the term *autopoietic machine* for systems such as living organisms that maintain themselves by producing their own components. They emphasized that the components of such systems "1) through their interactions and transformations continuously regenerate and realize the network of processes (relations) that produced them; and 2) constitute it (the machine) as a concrete unity in the space in which they exist by specifying the topological domain of its realization as such a network" (Varela, 1979, p. 13).

Both characteristics of autopoietic machines deserve comment. First, to regenerate themselves, such machines require machinery that is directed toward making their own components. Such machinery requires a source of energy and raw ingredients for constructing itself. Hence, the system must be an open system situated between an energy source (a more structured, less equally distributed, state of matter) and an energy sink (which is less structured). But crucially it must capture this energy in a useable format (e.g., gradients, chemical bonds) so that it is available for energy demanding operations. Second, the smooth operation of the system depends upon the organization of the components so that different operations are orchestrated (e.g., energy and raw materials are delivered to the location where new parts are synthesized). Minimally, this requires some way to keep needed constituents together and separated from the environment in which the system is situated. That is, the system requires a partially porous boundary (e.g., a semi-permeable membrane) that allows selected materials to cross. Moreover, the system itself must be able to control what is admitted and what is expelled from the system. Ultimately, because the concern is with a system that remakes itself, this boundary needs to be one of the system's own making.[20]

[20] For a stimulating and provocative development of how a metabolic and a mebrane system, together with a control system, can result in a chemical system capable of exhibiting the basic features of living systems, see Gánti (2003).

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